STATUS OR RECOMMENDATION: SELECTING THE TYPE OF INFORMATION FOR DECISION AIDING

A Thesis Presented

by

WILLIAM M. CROCOLL

Submitted to the Graduate School of the
University of Massachusetts in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN INDUSTRIAL ENGINEERING
AND OPERATIONS RESEARCH

May 1990

Department of Industrial Engineering and
Operations Research

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CHAPTER 1
PROBLEM STATEMENT

It is 0450 AM and the sky is just beginning to show the dawn of a new day. Sp4 Eagle-eye and PVT Sharpshooter have been awake for the last 50 minutes scanning the sky for hostile aircraft.

They are one of the Stinger Teams supporting 1-62 Infantry Battalion (Mechanized). The battalion is in an assembly area preparing for a movement to contact at 0500 hours. The battalion is considered a high priority target for enemy aircraft (due to their vulnerability at this phase of the operation). An intelligence report indicating that the enemy will attack this morning has raised the hair on the back of Sharpshooter's neck. Eagle-eye and Sharpshooter know the enemy likes to attack assembly areas and do so early in the morning to take advantage of both the congestion of assembly areas and degraded visibility of dawn. They are ready!

The job of this air defense team is to acquire and quickly engage enemy aircraft before severe damage can be caused to the battalion. Suddenly, as if on cue, a voice over the radio squalks: "Dynamite from the east, Dynamite from the east! (code word for hostile aircraft). PVT Sharpshooter, the gunner, moves quickly into his hasty firing position on top of their armored personnel carrier. His job is to acquire the target, track it until it is within range, and engage upon command from his team chief. Sp4 Eagle-eye is the team chief. His job is to acquire the target, make a target identification and give his gunner the command to engage (shoot) or not.

From a cognitive perspective, Eagle-eye must accomplish four tasks: (1) acquire the aircraft, (2) identify the aircraft (the target aircraft is classified as friendly, hostile or unknown), (3) make an engagement decision (i.e. to fire or not) and (4) respond accordingly (give the appropriate command to his gunner). These cognitive components can be analyzed within the framework of the information processing approach and more specifically a schema model. Schema theory involves matching the perceived material with a structured mental representation of the user's general knowledge of the topic. A schema provides a basis for categorizing, selecting, deleting, abstracting, consolidating and organizing information. Once learned, it can be employed to comprehend other situations with similar structures. A schema then is an ordered checklist or analytical template which structures perception and information processing (Hopple and Halpin, 1985), represents the combination of cognitive components required for a task as well as the order in which they are to be accomplished.

The schema for this task would be as follows:

(1) Target Acquisition. A need for action is generated when the aircraft is spotted. This is the detection of the presence of an aircraft.

(2) Target Identification/Recognition. This again involves the perceptual processes in a data-driven bottom-up fashion. A feature matching process occurs between the target aircraft and a memory set of previously learned aircraft. The search can result in a match (identifying the target as friendly or hostile) or no match (unknown).

(3) Decision Making. This component determines a course of action. An action is determined in a rule-based fashion where pre-established rules are applied. The rules combine aircraft type and current weapon control mode to arrive at the appropriate decision.

(4) Response. The decision is carryed out through some physical action (i.e. giving the order to fire or not).

In this task, Eagle-eye is required to visually identify the aircraft before giving the command to fire. Even with this doctrinal constraint, Sp4 Eagle-eye would welcome some assistance.

At one level, he does not require assistance to accomplish this task. He can operationally perform all of the components of the task and determine an ultimate decision individually, which is the current method of accomplishing this task. But on another level, considering the speed of current aircraft, their increased weapon ranges and the possibility of degraded visibility (from weather or smoke), some type of assistance (i.e. information on the aircraft) might enhance his ability to make a faster and more accurate decision.

There appears a need for some sort of decision support system (decision aid) to assist Eagle-eye in this decision task. The nature of this decision environment (i.e. short time frame to make the decision and high cost of an error) makes this assistance all the more crucial.

In general, during the last ten to twenty years, command, control, communication, and intelligence (C^3I) has become increasingly important to the war fighting capability of the military forces (Tachmindji, 1986). Military decision makers will be inundated with voluminous amounts of information which will have to be processed rapidly to enable leaders to act within the decision

cycle of the enemy. Expert systems and other artificial intelligence applications will become a necessity (Wolfe, 1986). Each of the services has spent millions of dollars over the last decade attempting to acquire tactical command and control systems that would provide centralized information for the decisions maker's use in planning and control of forces (Teates, 1986). The Defense Advanced Research Project Agency (DARPA) and the Strategic Defense Initiative Organization (SDIO) are supporting work in these areas (Shumaker, 1987). In particular, the army is currently working on a hand held device to assist the Stinger team chief in the field. The tradeoffs associated with this sort of decision support system are the quicker and more accurate engagement of aircraft versus the cost of such an aid.

This research is motivated by an interest in human interaction with decision support systems and the more effective accomplishment of the Air Defender's mission. It has led to the investigation of one of the aspects of such a decision aid (the cognitive content of the information conveyed by the decision aid) and human interaction with decision aids in general. The objectives of this research are to determine:

(1) the effect of decision aiding on decision making performance in a military command and control situation and

(2) the cognitive content of the information that is most effective in this situation.

CHAPTER 2

LITERATURE REVIEW

Introduction

There are a number of areas in the literature related to the effect of the type of information presented to a user by a decision support system on the total system performance. In this section those findings and how they relate to this research will be discussed. Those areas are: human-computer interaction in complex dynamic systems; decision support technology, with emphasis on the human interaction with the system; and the cognitive psychology research on semantic priming.

Complex Dynamic Systems

There is an increasing trend towards a substantial use of automation in the control of complex, dynamic systems. The result is larger, more complex systems with centralized control ~~(Woods and Roth, 1987; Rasmussen, 1986)~~. This increasing complexity of technological systems and increased use of automation has shifted the demands on human performance from a mechanical/physical level to a cognitive level.

A key scheme for classifying levels of technology described by Kantowicz and Sorkin (1983, p. 7-9) focuses on the contributions of people and machines to the total system. At the lowest level the person supplies both the power and control of the system. A human using a shovel is functioning at this level. At the next level, the machine provides the power and the human provides the control.

An example of this is an operator using punch press. ᵢₑ third level has the machine providing power and information, while the human controls the functions. An operation in a process control plant is a good example of this. Finally, the highest level of technology has the machine supply the power, information, and control, while the human monitors the operation. A pilot flying an airplane on autopilot is an example of this level. This scheme clearly illustrates the changes in the human's contribution with the increased use of automation. The human has evolved from a doer into an information processor. The roles of automation and the human in these complex, dynamic systems will now be discussed.

Role of Automation

The role of automation in these complex, dynamic systems is to provide more powerful and efficient control. Automation takes over routine tasks such as data sensing, aggregation, and manipulation, as well as simple decision making, given well defined alternatives (Mitchell, 1986). The introduction of automation to accomplish these functions has changed the role of the human.

Role of the Human

The new role of the human is to act as a supervisor of the system with goal setting, problem solving and decision making as the primary tasks. The human's role is primarily passive, involving the monitoring of the system state. This role only changes when unexpected system events or failures occur (Mitchell, 1987). The human supervisor will carry out the functions that previously

required several people. The major function of the human operator is information processing. The human operator transforms displayed data into meaningful information and eventually into control actions (Mitchell, 1983). A key issue that arises with this new human role and function is the way that information is displayed to the human (Mitchell, 1986). This issue appears to be of primary importance to the cognitive interaction between human and the automation (computer) in these complex, dynamic system environments. To understand this interaction more fully, it is important to discuss the strengths and limitations of both automation and the human.

Strengths and Limitations of Automation

The strengths of automation will be addressed first, followed by the limitations. In this section, the terms computer and automation will be used interchangeably. In general, computers (1) do not become complacent or yield to distraction, (2) remember without error (save mechanical malfunction), (3) do not fatigue and can monitor continuously, (4) are not susceptible to context effects, and (5) they are usually not disturbed or degraded by environmental conditions (Chambers and Nagel, 1985). Also, computers can retrieve coded information quickly and accurately when specifically requested (McCormick, 1976, p. 261-262).

Computers do have some limitations however. They often do not indicate when something has gone amiss and that the limits of their capabilities have been exceeded (Borning, 1987). More importantly, computers are unable to effectively handle degraded information or novel situations with ambiguous conditions in which

previous guidance of an explicit nature is not available. In other words, their precision and reliability is impressive but in no way challenges the human intellect. They respond well to those situations anticipated by the system designers (Chambers and Nagel, 1985).

Strengths and Limitations of the Human

The strengths of humans lie mainly in their ability to be creative and reason inductively. Humans have a good ability to cope with ambiguous, vague or uncertain environments. They make inductive decisions in novel situations and generalize from analogous experiences, allowing them to improvise and exercise judgement (Chambers and Nagel, 1985). Humans are good at remembering principles and strategies, and then drawing upon these to make decisions and generate solutions to varied problems. In addition, they are also good at developing entirely new solutions (McCormick, 1976, p. 261-262).

There are a number of limitations that have been observed in humans in complex system environments that are important to discuss because these limitations are instrumental in the design of the human-computer interface. Those limitations focus on the information processing ability of humans. First, human ability to monitor changing information is fairly low. Monty (1973) found that subjects would make errors even in situations where they had to simultaneously monitor only two or three items of information. Second, studies of aircraft and helicopter pilots indicated an extreme difficulty in integrating large quantities of displayed data (Murphy, McGee, Palmer, Paulk and Wempe, 1978). In a similar type of

experiment, Bejczy and Paine (1977) showed that the additional effort expended in monitoring and integrating a larger input (number of sensors) is not offset by the increase in the completeness of information. The greater demands on the human information processing system resulted in degraded performance. Third, research by Rouse (1978a, 1978b, 1979) suggests that humans have a difficult time synthesizing meaningful information at the conceptual level from individual data items, and Laitos (1978) showed that such performance further deteriorates under stressful circumstances. Blumenthal (1977) also found that humans are limited by the capacity of short term memory and the difficulty in processing, synthesizing, and integrating multiple data items, as well as time constrains. Lastly, the research by Tversky and Kahneman (1981) showed that human decision making is affected by the way in which the situation is presented. Different decisions will be made based on the same information depending on whether it is presented in a positive or negative manner.

Mitchell (1983, p. 355) summarizes the implications of these limitations in this way. "The underlying message is clear: the human operator in complex systems can be expected to act with competence and confidence only when needed information is provided in a timely manner in a readably interpretable form." She recommends the use of integrated computer-based information displays to provide operators with information that is more compatible with their higher level information needs.

Summary

Based on the strengths of the human and limitations of automation, the human operator is likely to remain a critical component in the control of complex, dynamic systems. Therefore, a major design issue is how to use automation to enhance the effectiveness of the human operator. The goal is not to replace the human operator but rather to use automation to amplify human skills (Mitchell, 1987; Woods and Roth, 1987). Chambers and Nagel (1985) identify some major research and design issues that must be addressed in the use of advanced automation. Those issues are: (1) locus of control, (2) manual reversion, (3) error tolerance, (4) information transfer, (5) allocation of functions between the human and automation, (6) training, (7) operator/crew acceptance, and (8) decision aiding.

Of the new roles acquired by the human, decision making has emerged as the focal point of the often conflicting demands on human action. Chambers and Nagel have identified one of the functions automation can perform in complex, joint human-automation systems: aiding the human in the task of decision making. To enhance decision making performance, one might incorporate some type of automated decision support system. Advances in decision support systems (e.g. expert systems) have now provided that possibility in the quest to support human performance. Woods (1986) explains that these intelligent decision support systems strive to exploit the strengths of both the human and the computer components of complex systems. The literature on these decision support systems will now be addressed.

Decision Support Technology

There are a number of important issues related to the use of decision support technology in process control and military command and control, and the role of the human in these systems. Some of these issues will now be addressed.

Aidability Determination

Given that the strengths and limitations of both the human and automation are known, and adhering to the assumption that the use of automation to amplify human skills is desirable; the first determination to be made is whether decision aiding is warranted for the specific system/situation under consideration. Hopple (1986) discusses the generalized assumption that computerization is always beneficial. He called this "methidolatry." He suggests a framework for determining the aidability of the situation and the type of aiding that would most enhance total system performance. He considers two variable clusters: (1) those variables associated with the decision situation and (2) those associated with decision making functions or tasks. The resulting matrix constitutes the decision making opportunities. This framework will now be elaborated on.

The decision situation variables focus on the complexity of the decision to be made and the quality of the data input. He defines two general levels of decision complexity: (1) closed decisions—where decisions are both frequent and familiar and the course of action is straight forward (i.e., observed patterns of information are mapped directly to appropriate courses of action); and (2) open decisions—

where no self evident, obvious, a priori bounds exist on the possible solution set. The data input quality is given values of high or low.

Hopple clearly states that decision aiding systems are potentially feasible in all of the combinations, however the focus of the decision aid changes. He does, however, believe that decision aiding is most needed when input data quality is low and decision making time is limited (time stress).

The second variable is the set of decision making tasks or functions. The following breakdown of the four major decision making tasks is taken from Wohl (1981):

(1) stimulus/data exposure or gathering
(2) hypotheses/alternatives generation
(3) analysis and selection of one of the alternatives
(4) response

Hopple uses this two variable typology to suggest decision aiding application domains corresponding to steps in the decision making sequence. This typology allows the determination of the need for decision aiding, the aiding functions desirable (assimilation, interpretation, analysis, situation assessment, alternative generation, or solution recommendation), and which decision making tasks to aid.

Hopple's framework is generic in nature, but can be used to determine aidability in the arena of military command and control. In the military, command and control is perhaps the ultimate force multiplier (Heilmeier, 1986). The essence of command and control is decision making, and it has long been recognized that computers can be used to help make decisions (Teates, 1986). Military decision makers, although concerned with decisions of both large and small

consequence, are no less fallible in the use of logic and influence than are other professionals in their area of expertise. These human foibles can be specifically mitigated through the proper design and use of decision support systems. In addition, military decision makers, knowing the consequences of poor decisions and rushed by circumstances beyond their control, must often make their decisions under considerable stress (Teates, 1986).

Automated decision aids can help deal rapidly, consistently and accurately with the complex interrelationship of the many variables inherent to battle management (Flynn, 1987). Expert systems on the battlefield can provide both a better organized understanding of the battle situation, as well as better control of the resources available. The application of expert systems includes intelligence analysis, battlefield management, mission planning, assessments, and threat evaluations (Wolfe, 1986). In any high stress, high rate of information situation, human decision makers can be overloaded and become unable to assimilate and use all of the available data. This is particularly true in combat management where data must be evaluated and used effectively in managing weapons and making tactical decisions under strict time constraints. It is clear that automated decision aids would greatly enhance military command and control, and Hopple has provided a paradigm to examine each specific type of decision situation to determine if a decision aid is needed. The framework is most useful in determining which functions would be best performed by the decision aid.

Role of Decision Support System

One of the main functions of a decision support system in complex environments, such as military command and control and industrial process control, is to monitor that environment and present a summarized interpretation of that data to the decision maker to assist in the decision making process.

A decision support system can be responsible for finding/sensing, assimilating and integrating relevant data. However, the additional key responsibility/role of a decision support system is to interpret that data with respect to the domain tasks/goals and more actively assist the human in the decision making process, with the goal being higher quality and/or quicker decisions. Woods (1986, p. 172-173) describes the key role to be played by the decision support system as "supporting the user by providing informative counsel" such as:

(1) warning the user of potentially dangerous conditions

(2) reminding the user of potentially relevant data

(3) suggesting alterative response strategies

(4) performing information processing tasks

(5) enhancing the user's information extraction, problem structuring, and thinking.

The situation posed in this research falls into the closed decision/high data quality combination. The decision aid's primary function in this situation to aid information processing (i.e., assist the user in assimilating and interpreting the input data). In the case of a closed decision situation, the human knows the appropriate response for each type of input data and thus does not need assistance in

alternative generation. In the case of Eagle-eye and Sharpshooter, a decision support system would have the role of facilitating Eagle-eye's decision making ability (both accuracy and speed) by assisting in information processing. The goal of this human-machine system would be to maximize engagement of hostile aircraft, as quickly as possible, while preventing the engagement of friendly aircraft. For example, a decision support system might assimilate input data about an aircraft (e.g., altitude, speed, profile, Identification Friend or Foe response, and adherence to designated air corridors) provided by battlefield sensors. It would summarize and interpret that data, then present the summarized information to Eagle-Eye. The issues involved in that interface will be addressed in the human-decision support system interface section. Before that interface is addressed, the role and responsibilities of the human in this joint system will be discussed, as well as the major issues that arise with this introduction of automated decision assistance.

Role and Responsibilities of the Human

The introduction of an automated decision aid alters the role and responsibilities of the human and introduces some critical issues concerning the coupling of human and machine.

The role of the human in a decision aided environment is very similar to that of monitoring/supervising a complex, dynamic system without aid. The primary change is interaction of the human with an automated system which more actively assists the human in the decision making process rather than merely facilitate access to the data as discussed in the previous section on complex systems and the

display literature (Mitchell, 1983, 1986, 1987; Rasmussen, 1981, 1986; Coury and Pietras, 1989; and Coury, Boulette and Smith, 1989).

Perhaps the key responsibility of the human in decision making is accountability for the final decision. Fitter and Sime (1980) claim that the computer is not and should not be capable of interacting on an equal basis. The user should be the master, the computer a tool, with the responsibility of the ultimate decision resting entirely with the human.

Other responsibilities include detecting malfunctions in the decision support system, deciding when the current situation is outside of the capabilities of the decision support system, and determining when to exclude the decision support system from the decision making process.

Introduction of a decision support system raises some very important issues. The first one relates of the human's confidence in the decision support system's output. The user of a decision support system is rarely incompetent in the problem domain, thus will be in the position to (at least subjectively) make an assessment as to the reliability of the output of the decision support system. Woods (1986) claims that the value of the information provided by the decision support system degrades rapidly if it exhibits a bias for or against possible events, even if the decision support system is a sensitive detector. This indicates that the human's confidence in a decision support system will be affected by both its sensitivity and its bias.

A closely related issue concerns the ability of the human to discriminate the correctness of the decision support system's information/output. Does the human have the level of expertise to recognize erroneous output or when a situation is beyond the decision support system's capabilities?

The third issue synthesizes the first two issues. It relates to the human's perceived or actual authority to override the decision support system's output. In a discussion of the changing roles and responsibilities of the decision maker upon the introduction of automated decision support, Fitter and Sime (1980) indicate a feeling that automated systems can get out of control. Their rationale is that the people responsible for its use may not comprehend the workings of the system thus leading to their hesitancy in overriding the automated decision on some or all decisions. Their contention was described in the portion of this section which discussed the human's responsibilities, specifically that the automated assistance was a tool to be used by the human. This will be discussed in detail in the human-decision support system interface section.

The fourth issue is the seriousness of the consequences of the wrong decision. If the consequence of a potentially wrong decision is very great, the human may choose a cautious strategy. How such strategies will affect the human's use of decision support system is unclear.

The fifth issue is the speed at which the decision must be made and how this affects the use of the decision support system's output.

The sixth issue is the potential loss of cognitive skills. Decision makers may decide that the machine can solve all of their problems

and thus they may cease perfecting their problem-solving skills. The loss of cognitive skills, either from deterioration or the failure to continuously enhance (update) needed skills has been addressed as a critical area of attention when considering the use of automated decision support systems. Work in process control emphasizes that knowledge only becomes operationally effective if it has occasion to be used (DeKeyser, 1986). Issues on loss of cognitive skills are related to the loss of perceptual-motor skills that arise in the control of automation. Will the human be able to function if the system is malfunctioning or is unable to provide assistance (Hoogevens Report, 1976; Chambers and Nagel, 1985; and DeKeyser, 1986).

The last issue is the reliability of these advanced technology systems. As the complexity of automated systems increases, the opportunity for system failure concomitantly increases and reliability decreases (Borning, 1987). Borning also discusses some of the sources that can contribute to this potential system failure, including: incorrect or incomplete system specifications, hardware failure, hardware design errors, software design errors and human errors. With complex, normally highly reliable systems, a failure may be caused by an unusual combination of problems from several sources. He cites two excellent examples in the national defense arena illustrating the potentially disastrous consequences of system failures. The first was in 1960 when the warning system at Northern Air Defense Command indicated that the United States was under massive attack by Soviet missiles with a certainty of 99.9%, when, in fact, the early warning radar in Greenland had spotted the rising

moon. None of the system designers had anticipated that the system would respond to the moon.

The second event occurred in 1980. The display system at the Command Post of Strategic Air Command in Nebraska indicated that submarine launched ballistic missiles were headed toward the United States. The displays suddenly cleared. Shortly thereafter, the warning indicated the intercontinental ballistic missiles had been launched toward the United States. The cause was a failed chip in the computer that was used as a communications multiplexer to send messages. When the chip failed, the system started filling in the "missiles detected" field in the message with random digits instead of zeros. These two examples show both software and hardware failures that could have resulted in a nuclear exchange between the United States and the Soviet Union. These situations also illustrate how the strengths of the human decision maker compensated for the weakness of the computer, and the critical importance of the human being ultimately responsible for the final decision and response.

There are also design and development issues that will need to be addressed in the actual construction of a decision support system. These include (1) task component analysis, (2) knowledge acquisition, (3) expert selection, (4) problem solving strategy to be used by the system, (5) allocation of functions between automation and the human, (6) knowledge representation, and (7) the user interface.

As explained in the Problem Statement section, the focus of this research is on how the type of information, presented to the human by the decision support system, affects total system performance.

The literature review clearly illustrates the highly interactive nature of decision support systems, supporting the hypothesis that the user interface is critical to the success and acceptance of the decision support system (Wheeler, 1989). However, prior to focusing on the human-decision support system interface, a review of the major research issues in human-decision support system interaction is warranted, as well as consideration of the cognitive demands placed on the human when interacting with a decision support system.

Major Research Issues and Cognitive Demands

The are a number of major research issues associated with the consideration of the design and development of a decision support system and the interaction of the system with the user. Some of those key research issues are:

(1) Determine if automated assistance is needed

(2) Determine how the aid will assist the user (i.e., the decision making tasks that will be the focus of the decision aid)

(3) Determine the functions the decision support system will perform and the functions the user will perform

(4) Determine how the decision support system will present information to the user

(5) Determine how the human will be affected by the use of automated assistance (confidence in aid, propensity to override, ability to discriminate incorrect assistance, strategy selection, skill loss, etc.)

Mitchell (1986, p. 356) highlights the importance of understanding the cognitive components involved in the decision making task and their impact on the design of the display. She states: "The design of the display is a critical determinant of computer-based display's effectiveness in real-time control environments. To answer the questions of what information to display, when, and in what form requires careful and detailed representation about the cognitive needs of the human controlling the system (i.e. the design must be based on a model of human decision making in the system)" With the introduction of a decision support system, the cognitive demands and subsequent stages of decision making are:

(1) Identification of the state of the system/environment.

(2) Determination of the alternatives (solely or with the assistance of the decision aid) (usually has to be accomplished quickly).

(3) Perception, integration, interpretation and storage of information received and processed by the decision aid.

(4) Analysis of the time available to make the decision.

(5) Analysis of the consequences of wrong decision (i.e., the effect of inappropriate aid on the acceptance of the decision aid's output).

(6) Comparison of the user's decision to the decision aid's recommendation.

(7) If the decision by the decision aid and the user's decision are incongruent, then a mechanism for resolving the conflict must be present.

(8) Make the final decision.

(9) Respond with the appropriate action.

With this summary of the major research issues and cognitive demands associated with human-decision support system interaction in mind, recall that one of the critical aspects of this interaction is the manner in which the decision aid presents information to the user. The literature on that interface will now be addressed.

The Human-Decision Support System Interface

Designing systems to meet the needs of users is the goal of human factors, and this must be accomplished at both the physical and cognitive interface (McDonald, 1982). Unfortunately, most human factors guidelines for computer displays focus on the physical interface to ensure that human sensory limits are not exceeded and that users can effectively access data. It rarely, if ever, addresses issues concerned with using the computer displays to aid human performance of domain tasks (Woods, 1985, p. 325). States Woods: "This is particularly important in complex environments such as military command and control and process control (e.g., nuclear, thermodynamic, and chemical) where the goal is more than a useable interface. The interface must support effective performance in tasks such as situation assessment, fault management, problem solving, planning, and decision making." Landauer, commenting on human-computer interaction in the year 2000, said "at least as important as new hardware or new modes of interaction, such as voice or touch, will be the great expansion in the number and kinds of cognitive tasks that will be supported" (Landauer, 1986, p. 253). Chechile et

al. (1989, p. 32) said "we believe the cognitive quality is perhaps the most important level of analysis in considering the human engineering of a display."

Focusing on the physical aspects of the interface can be broken down into two subcategories: concentrating on the ergonomic aspects of the system, or concentrating on the visual (perceptual) aspects of the information displayed. In the latter, the focus has been on image parameters. This includes such things as contrast, luminance, character legibility, and resolution (McDonald et al, 1982; Eggleston et al., 1986). Although these are indeed critical aspects of the interface.

However, if the purpose of the display is kept in mind (i.e., to communicate with people with respect to their knowledge, goals, tasks, and situation), and Mitchell's contention that the human operator in complex systems will act with competence and confidence only when needed information is provided in a timely and interpretable form; another critical area of the interface becomes apparent: the cognitive content.

Much work has been done in an effort to illustrate the importance of the cognitive content and cognitive quality of the interface on overall system performance. Eggleston et al. (1986) define the cognitive quality of the interface as the relative ease or difficulty a person has in deriving <u>meaning</u> from a particular representation. This quality is the cornerstone of the design of the cognitive interface, with the focus on what is "conveyed" not merely displayed. The process broadly entails (1) obtaining measures of relevant cognitive characteristics of the intended user's knowledge

representation for the task domain, and (2) mapping those data to an interface configuration (McDonald, 1982). McDonald describes a study simulating a menu-based control system that examined the effects of organization (i.e., the arrangement of data in informational categories) on performance. Multi-dimensional scaling and hierarchical clustering were used to organize the subsets. The results showed that there was a benefit from the organization, with the trend in all dependent measures favoring the organized menu. This study illustrates the enhancement in performance when the system's representation closely matches the user's representation.

Rasmussen (1981) conducted a cognitive task analysis on process control operators' diagnostic strategies of fault finding behavior. One of the strategies identified by Rasmussen (called topographic search) is performed by mapping of the system against normal or reference conditions through which the extent of the potentially bad field is gradually narrowed down until the problem area is identified. For this to be effective, the operator needs;

(1) a model of the structure of the system with various levels of abstraction;

(2) search rules or heuristics;

(3) a model of the normal operating state of the system;

(4) relationships among data rather than just the magnitude of the variables.

Rasmussen claims that current nuclear power plant control rooms do not support these needs since there is only one level of representation of plant state (i.e., the operator must construct the other levels mentally). The current one measurement/one indication

display philosophy does not show relationships between the data, requiring the operator to mentally integrate the data. The result is a mismatch between the demand for efficient diagnosis and the characteristics of the interface, thereby increasing mental workload and the possibilities for errors. The Three Mile Island accident is an excellent example of the need for emphasizing the cognitive aspects of the interface. The investigation of that accident revealed that the necessary information was, in general, physically available, but not operationally effective. The operators could not integrate the separate pieces of information (data) to make the correct decisions (Joyce and Lapinsky, 1983). Rasmussen's model suggests that the display should match a useful mental model of the functional structure of the system at the appropriate level. Such a display would greatly reduce the information processing required by the human in preparation of making a decision.

There are some key problems associated with data displays that neglect the cognitive capacities of humans discussed earlier. Two of the factors that have potentially devastating effects on performance are (1) getting lost, and (2) cognitive tunnel vision (Woods, 1984).

Getting lost means that the user does not have a clear conception of functional relationships within the system. This results in inefficient and incomplete utilization of display system data resources. A study by Robertson, McCracken, and Newell (1981) points out that the "getting lost" phenomenon occurs even in systems which provide display selection mechanisms in accordance with accepted human factors guidelines.

Cognitive tunnel vision (Moray, 1981) occurs when the user's attention is locked on a subset of variables to the exclusion of all others. Focusing attention on a subset of variables can lead to a decrement in performance, especially when state identification requires integrating data from several sources.

In an attempt to determine if a summary would prevent the user from "getting lost," Engel, Andriessen, and Schmitz (1983) used a cognitive engineering approach that provided an overview of the display structure as well as summary status data to improve total system performance. With this approach, the user did not have to remember or construct a mental model of the data structure. For the data summary to be effective, however, the relationships that are important to the user's task must be portrayed. Merely summarizing data is insufficient. For example, user performance suffered in an example from Holnagel (1981) because the summary did not portray the important functional relationships.

As an interim summary, the physical guidelines on the design of computer displays generally attempt to ensure that human sensory limits are not exceeded. The implicit assumption is that if the user can successfully process system data, then s/he will find, integrate, and interpret all of the relevant data at the correct time. However, problems such as "getting lost" and "cognitive tunnel vision" demonstrate that the successful processing of data does not guarantee successful information extraction and optimal task performance (Woods, 1984).

The analysis of what makes data informative shows that the question of what constitutes a good display is directly linked to what

the human user needs to know in order to accomplish the domain task. In other words, a good display can not be constructed or judged unless one knows what the display should communicate to the user (Woods, 1985).

The implications of this concept of the cognitive quality of an interface for human-decision support system interaction should now be very clear. Once the decision support system assimilates and interprets all of the system/environmental data and is prepared to present information to the decision maker; a determination must be made on the type of information the decision aid present to the decision maker. The decision aid must communicate with the user with respect to the user's knowledge/mental model of the situation, goals, and tasks, as well as providing information closest to that needed by the human to make the decision? Borning (1987) cites a comment made by a defense industry manager stressing this point, "the most challenging information problem in the modern C^3I systems is the merging of diverse data into a single, coherent representation of the tactical, operational, or strategic situation."

Woods (1986) claims that the key to effective application is a joint human-machine cognitive system. He uses the term "cognitive coupling" to emphasize the closeness that is imperative in the design of the human-computer interface. He proposes a design focus that is (1) problem driven (as opposed to technology drive), (2) involves a detailed task analysis of the cognitive components of the task, and (3) is centered on the joint cognitive system. He claims that improved joint system performance depends on a shift in emphasis away from a display of the data as signals towards a focus on

communicating the meaning of the data. He hypothesizes that a decision support system should act as an informative counsel, not making or recommending solutions, but aiding the user in the process of reaching a decision. He further states that if the decision aid provides some form of recommended solution, the user should still be ultimately responsible for the outcome.

Smith (1981) claims that work in the area of person-machine systems has established that a machine locus of control can have strong, negative effects on the user and thus total system performance. Fitter and Sime (1980) also point out that problems with user acceptance are often symptoms of underlying deficiencies in the cognitive-coupling between the human and the machine.

Sorkin and Woods (1985) view a joint cognitive system as two decision makers in series. In the first stage, the automated subsystem makes a decision about the state of the underlying process. In the second stage, when alerted, the human uses this evidence and summary analysis in making the ultimate decision. Sorkin and Woods claim that joint systems can be enhanced or degraded based on the interaction of the subsystems of human and machine. The value of the output from the automated subsystem is best considered as information or evidence to be used by the decision maker, rather than a solution to be accepted or rejected.

When a decision aid produces a recommended solution, the human user remains responsible for the outcome. The user, of course, has the authority to override the machine, but this type of "cognitive coupling" has strong negative implications. Since the user's only option is to accept or reject the recommendation, there is

a great danger of a responsibility/authority double bind. This is a situation states Woods (1986) where the user either always rejects the recommendation (perhaps by finding or creating grounds for decision aid unreliability) or the user totally abrogates his decision responsibility (i.e., the user does not override the decision aid's recommendation, regardless of the circumstances). This responsibility/authority double bind has been observed with non-AI decision aids that output solutions (Fitter and Sime, 1980) and with increases in control automation that fail to address the operator's new role as supervisor of the automated resources (Hoogovens Report, 1976).

The social psychology literature on human-human advisory interactions also illustrates the negative effect of providing a recommended solution to a problem. Coombs and Alty (1980) found that unsatisfactory human-human advisory encounters occurred when the advisor offered a solution with little or no feedback about how the problem was solved. On the other hand, in more successful encounters, control of the interaction was shared in the process of identifying the important facts and using them to ultimately solve the problem. Kabanoff (1985) states that people are sensitive to and protect their roles in groups or dyads. Any behavior on the part of another which fails to recognize this, be it rational or not, is threatening. Kabanoff also reiterates a key idea in Brehm's Reactance Theory which suggests that people will act or change their attitudes in a way opposite to that desired by an influence agent if they perceive that their freedom of choice or autonomy is threatened by the influence agent. The parallels between the characteristics of

unsatisfactory human-human advisory encounters and the characteristics of a joint cognitive system are evident and would indicate that similar negative aspects will be seen in the interaction between a human and a decision aid. Given the danger of a responsibility/authority double bind and the negative effects described in the social psychology literature, a decision support system that offers solutions rather than informative counsel may not be an effective model for decision aiding.

There are various types of information that a decision support system can present to the decision maker. Some of these are: (1) historical, (2) predictive, (3) status, and (4) a recommendation (sometimes referred to as advisory or command information). The previous discussion on the joint human-machine cognitive system strongly suggests that the overall system performance is enhanced when the information displayed by the decision support system is presented as evidence rather than a solution/recommendation to be accepted or rejected. This argument, played a large role in the decision of which types of information to investigate in this research. Recall that the focus of this research is to investigate the effects of the type of information presented by the decision support system on human decision making. In particular, this research is concerned with determining how performance is affected when a decision maker is presented with status information (evidence), recommendation information (solution), or both types of information in a target engagement task.

If the goal then is to "fit the system to the user," then systems must be designed in such a way that the number of errors committed by the users is reduced, and the amount of time required to accomplish the task is minimized. "Fit" in the context of this research focuses on the meaning (content) of the information presented by the decision aid in its attempt to provide assistance to the decision maker.

In the scenario facing Eagle-eye and Sharpshooter, a decision aid could potentially increase the accuracy of the decision and reduce the amount of time required to make the correct decision. The role of the decision support system would be to assist Eagle-eye in processing information by assimilating and interpreting input data associated with aircraft parameters. The key issues in this research are: (1) to determine if a decision aid will enhance performance in the type of task facing Eagle-Eye and Sharpshooter, and (2) to determine the best type of decision information to be presented to Eagle-eye. Should it present an aircraft status (i.e. friendly, hostile or unidentified) or a recommendation (i.e. fire or no fire) or maybe both?

Based on this consideration of human interaction with a decision support system and the analysis of the cognitive components of the task, there is also an area of cognitive psychology research that needs to be discussed. In analyzing the cognitive components of the task in this research, a pattern emerges that appears similar to the cognitive components of the tasks in the semantic priming research. The literature on that research will now be addressed.

Priming

The concept of priming arose from the Spreading Activation Model (Collins and Loftus, 1975), a semantic network model emphasizing the relationship among concepts. The Spreading Activation Model assumes that when a concept is processed, activation spreads out along the paths of a network, with effectiveness decreasing as it travels outward. The idea of activation spreading throughout a semantic network of interconnected concepts provides a clear picture of semantic relations among concepts. The success of this model, however, depends on how well it can account for experimental results. One such result is the effect of semantic priming. Priming occurs when a decision about one concept affects a subsequent decision about another concept. The basic paradigm involves the use of primes in certain tasks to determine whether performance has been enhanced usually in terms of reduction in response times.

Evidence of the priming effect was found in the lexical decision task (Meyer and Schvaneveldt (1971, 1976). In their research, subjects were required to judge whether a string of letters formed a word. Some of the strings were meaningful words (e.g., butter) and some were not (e.g., nart). Each trial consisted of a pair of the strings, the second string presented immediately after subjects made decisions about the first string, and the measured variable was response time The most interesting results arose when the two strings were both words. If the two words were semantically related, the subjects were faster in verifying that the second string was a word than if the two words were unrelated. For example,

subjects verified that *butter* was a word faster if it was preceded by *bread* than by *nurse*. This supported the idea that the processing of one word appeared to facilitate processing of a related word. Meyer and Schvaneveldt argued that identification of the first word caused activation to spread from the word's location in the lexicon to the location of the corresponding concept in the semantic memory, and then through the semantic-memory network to the locations of related words. When the second string was presented, processing already had a "headstart." That is, the excitation from the first word reduced the amount of additional activation needed to reach the decision criteria. As a result, less processing of the second word string was required before response could be made, and it was made more quickly.

Further evidence for the priming effect was found in a study by Neely (1977). In this study, subjects made a lexical decision about a string of letters that was presented following a prime word. When the prime word was the name of a category and the letter string was a word that was a category member, responses appeared to be automatically facilitated. This suggests that processing of the category name (the prime) spread activation to its members. In general, these two studies illustrated that when subjects make two consecutive semantic decisions, response time is facilitated if those decisions are made about related items. This suggests that the initial semantic processing spreads activation, which speeds later processing.

The usefulness of priming in a problem solving task has also been studied. Dominowski and Ekstrand (1967) reported that prior

exposure to the solution word or to an associate of the solution word decreased solution time in an anagram solving task. Seidenstadt (1982) also conducted research on priming in a problem solving scenario. He tested 121 subjects on 12 single-solution anagrams. Each anagram had either a category label prime, list-item prime, or no prime. Compared with the no prime condition, both of the other priming conditions produced significant reductions in solution time. These results suggest that the priming effect can be found in problem solving.

The priming effect is important to decision aiding for the following reason. Since the purpose of a decision aid is to present information to a decision maker to enhance performance, decision aiding is then analogous to priming. Subjects in this research will likewise be required to make a decision about a related concept that is presented following various types of primes (information from a decision aid). The cognitive components will include the processing of a prime (decision information) followed by a required decision about a concept related to the prime. Thus, the cognitive components of the decision making task in this research bears striking similarity to the word recognition and problem solving tasks in the priming literature. Since the cognitive task structure in this research is analogous to that in the earlier priming studies, the basic priming experimental paradigm will be used to investigate the effects of priming on a decision aid assisted decision making task. And, if the performance of the decision maker can be enhanced, what form should this priming take (i.e. what should the content of the priming information be)?

CHAPTER 3

RESEARCH RATIONALE AND OBJECTIVES

As evidenced in the literature review, there are a number of important research issues. The priming research has shown that priming an individual can have a positive affect on task performance in the realm of word recognition and anagram problem solving. One of the objectives of this research is to determine if a similar effect can be found in a more complex decision making task. The human-machine research has also shown that the interaction between the human and the system, especially with respect to the way in which the information is displayed, plays a large role in the performance of a task involving a human and an automated decision aid. A second objective of this research is to determine the most effective content of that interface in a more complex decision making environment. Specifically, this research investigates the effect of the type of information (semantic content) presented by a decision aid on the performance (in terms of accuracy and speed) of the human.

Computer technology is emerging at a far greater rate than the ability of human factors research to rigorously evaluate its effectiveness. The reliability and effect on operator performance and workload of such technologies are critical issues where human decision making is time-constrained and the consequences of human error may be very expensive or even catastrophic (Mitchell, 1987). With the increasing commonality in the use of automated decision aids and thus the emergence of joint human-machine cognitiv-

systems, a determination must be made concerning the way in which that critical automated assistance is presented to the human.

The proposed experiment is an attempt to do that in a complex decision making environment (i.e., aircraft engagement) where the decision must be made quickly and there is a high cost of an error.

The global research objective is to improve the understanding of human decision making in demanding applications such as process control and military command and control systems. The specific objective of this research relate to investigating the effect of decision aiding on decision making performance. Performance refers to a person's ability to quickly and accurately process information and make a decision. The experimental issues of importance to this research are:

(1) Determine the effectiveness of decision aiding in facilitating both more accurate and quicker decisions

(2) Determine which type of decision information is most effective

The approach will be to present scenarios, similar to the one facing Sp4 Eagle-eye, to an experimental subject. Subjects will be required to: (1) learn a set of friendly aircraft, a set of hostile aircraft, and two sets of engagement decision rules; (2) visually identify a target stimulus (aircraft); (3) decide whether or not to fire at the aircraft in accordance with the decision rules; and (4) respond as quickly as possible.

Once training and baseline performance measures have been obtained, subjects will be presented with assistance from a decision aid prior to the presentation of an aircraft for identification and prior to the decision of whether to shoot or not. The assistance will vary in type and serve as both the priming information and the automated assistance. The accuracy of the decision aid will be set to 96% (a pilot study indicated that every subject quit using the decision aid totally after approximately 30-40 of the 216 trials when the accuracy level was 91%). By designing the task this way and presenting information from a decision aid, this experiment will be able to determine the effect of priming in a decision making task and determine which type of decision aiding information is most effective.

CHAPTER 4
EXPERIMENT

Decision Strategies

The are a number of possible ways that this task can be accomplished, when the subject is presented with the priming information. In order to address the hypotheses of this research, these decision strategies that can be used by the subject must first be defined. The predictions of this research will be based on these strategies. These decision strategies were developed by examining the cognitive components of the task, coupled with the type of decision aiding information presented.

The first condition is one where the subject is primed with the status (S) information. Status information is defined as friend, hostile, or unidentified.

The strategy for status (S) information:

-read status information
-identify target (with focused attention, {primed})
-make engagement decision
-respond

The second condition, when the subject is primed with the recommendation information, is a bit more complicated. Three different possible strategies are available.

The first one, labeled $\mathbf{R_a}$, is:

-read recommendation

-map (translate) recommendation to possible status

-identify target (again with focused attention)

-make engagement decision

-respond

The second strategy ($\mathbf{R_b}$) in this condition is:

-read recommendation

-store recommendation

-identify target

-make preliminary engagement decision

-compare to recommendation from decision aid

-make final engagement decision

-respond

The third strategy ($\mathbf{R_c}$) in this condition is:

-read recommendation

-see target (maybe identify)

-respond immediately with the decision aid's recommendation

The third condition, when the subject is primed with both status and recommendation information also has three possible strategies.

The first one (S/R_a) is:

-read information (and ignore recommendation)

-identify target (with focused attention from status info)

-make engagement decision

-respond

The second strategy (S/R_b) in this condition is:

-read S/R information (and store recommendation)

-identify target (with focused attention from status info)

-make preliminary engagement decision

-compare to recommendation from decision aid

-make final engagement decision

-respond

The third strategy (S/R_c) in this condition is:

-read S/R information (and ignore status)

-see target (maybe identify)

-respond immediately with decision aid's recommendation

The control group will not receive any priming and be labeled NP for no priming information.

The hypotheses, which are based on these strategies, the literature on priming, and the literature on human-machine cognitive systems, are presented below.

Predictions

Accuracy

Strategies R_c and S/R_c will have the lowest accuracy due to the blind adherence to the decision aid. An assumption here is that the subjects would be better than 96% with no assistance. Subjects utilizing this strategy will systematically choose the incorrect decision whenever the decision aid recommends the incorrect decision. The no priming information (NP) condition would expect to have the next best accuracy. Their accuracy will be strictly based on their skill in identifying the aircraft and choosing the correct engagement decision, based on the weapon control mode they are in. The status (S) condition, R_a and S/R_a strategies will be slightly more accurate. They will benefit from the decision aid while still being able to catch the incorrect information from the decision aid. The most accurate would likely be the R_b and S/R_b strategies, due to the comparison step in their decision making. They will, in a sense, be double checking their decision against the one presented by the decision aid prior to making their response. The equation illustrating the accuracy hypothesis is:

$$(R_c = S/R_c) < NP < (S = R_a = S/R_a) < (R_b = S/R_b)$$

Based on the instructions "accuracy is mandatory and speed is crucial," accuracy is expected to be high across all information types and strategies. The differences in accuracy are predicted to be very small and may not even be significant except for the R_c and S/R_c

strategies. Thus the second set of predictions concerning response time will be critical in assessing the differences in performance based on type of decision aiding information.

Response Time

Due to strategies R_c and S/R_c resulting in an immediate response using the decision aid's recommendation, these strategies will produce the fastest response times. Response times may even be lower than the time it takes to identify the aircraft, due the subjects sole reliance on and immediate response to the decision aid.

The three strategies that take advantage of the status information: S, R_a, and S/R_a (explicitly in S and S/R_a and converted in R_a) will have the next fastest response times. This strategy benefits fully from the category priming effect. The no prime (NP) condition will follow.

Strategies S/R_b and R_b will produce the slowest response times. The increased latency with these strategies will be due to the additional cognitive step of comparing their decision with that presented by the decision aid prior to responding. Strategy S/R_b should be slightly faster than R_b because of the assistance of the status information. The response times should follow this pattern:

$$(R_c = S/R_c) < (S = R_a = S/R_a) < NP < S/R_b < R_b$$

This research will attempt to look at not only the overall effects of the different types of information, but what strategies are utilized by subjects when presented with the various types of information and how this affects their accuracy and response times.

Method

Subjects

The thirty two subjects were volunteers from the University of Massachusetts community. Compensation for the 60-120 minute long session was based on a $5.00 per hour rate. All subjects had no previous military service. All subjects that completed the experiment had to meet a criteria level of 95% correct on the last 40 trials in Session 1, Aircraft Identification. This was to ensure that there would not be large error rates based on the failure to be able to identify the aircraft. The subjects were assigned to the condition groups randomly with the caveat that they could be assigned to a certain condition to assure that the groups were not significantly different. In those cases the assignment to condition was made based on the response time of correct responses of Session 1. The subject was placed into a group which would keep the groups response time averages for Session 1 as close as possible. This assured that there was no difference in the groups' average response time in that session. This assured that any differences between groups would be due to information type and not due to the differences between the groups.

Stimuli

The stimuli for this experiment consist of the graphic representations of 38 aircraft. The representations are of the side view and are black with white to define internal features. The stimuli are approximately two inches long and 1/2 inch tall. There are two categories of aircraft type, rotary wing (helicopters) and fixed wing (jets). There are 25 fixed wing and 13 rotary wing aircraft. The aircraft are divided into three categories of identification; friendly, hostile, and unknown. Ten are friendly (four helicopters and six jets) and ten are hostile (four helicopters and six jets). There are 18 unknown aircraft (five helicopters and 13 jets). Six unknown aircraft (two helicopters and four jets) are used for the training session on aircraft engagement. The other 12 unknown (three helicopters and nine jets) are used in the two test sessions (there are four sessions in the experiment)

The sequential presentation of the aircraft occur in a random order in both the training and test sessions. Each subject will undergo a total of 580 trials (304 training and 276 test). All subjects will receive the exact same training, thus will see the 304 trials in the training session in the same order. The first 200 trials in the training consist of ten replications of the 20 friendly and hostile aircraft. The last 104 trials in the training session are broken down into two blocks of 52 trials in each weapon control mode (tight and free). Of the 52 trials in each block, each friendly, hostile, and unknown (the six earmarked for training) aircraft appears twice.

In the test condition, the subjects will see the same set of 276 trials; however, for each subsequent subject, in a certain test

condition (e.g. status), the order of the 276 trials will be different (randomized). These 276 test trials are broken down into two sessions, consisting of two blocks each.

The first test session, called the Stimulus Only session, consists of 60 trials with two blocks (one for each weapon control mode) of 30 trials each. Within those 60 trials are 24 friendly aircraft (14 jets, 10 helicopters), 24 hostile aircraft (14 jets, 10 helicopters), and 12 unknown aircraft (the 12 for testing) (9 jets, 3 helicopters).

The 216 trials remaining are for Session Four (called the Priming Session), the second test session. Those 216 trials were divided into two blocks (again one for each weapon control mode) of 108 trials each. Within those 108 trials are 48 friendly aircraft (28 jets, 20 helicopters), 48 hostile aircraft (28 jets, 20 helicopters), and 12 unknown aircraft (nine jets, three helicopters). Thus the totals for that last session of 216 trials is 96 friendly aircraft (56 jets, 40 helicopters), 96 hostile aircraft (56 jets, 40 helicopters), and 24 unknown aircraft (18 jets, six helicopters).

The stimuli were presented on a Macintosh Mac II workstation using Hypercard. The stimuli used in this experiment are presented in Appendix A.

Task

The subject's task is to visually identify a target aircraft, and then, in accordance with the engagement decision rules corresponding to the current weapon control mode, make a decision to shoot or not to shoot at the aircraft . The response is to be made as quickly as possible by pressing a key indicating that decision.

Procedure

The subjects are instructed, in writing, as to the task they will be performing. They are also told that the single subject with the best overall performance will receive a bonus of $25.00. The general instructions are read to the subject. The subject then begins by studying cards of the 20 aircraft stimuli and the engagement decision rules for 30 minutes. The engagement rules are as follows:

(1) In weapon control mode **Tight:** Fire only at aircraft identified as hostile.

(2) In weapon control mode **Free:** Fire at any aircraft not identified as friendly (i.e. hostile and unknown).

The subject then begins the computerized portion of the experiment.

Session 1: Training on Aircraft Identification. The session consists of 200 trials. In each trial, the subject will see two screens sequentially. The first screen presents an aircraft. The subject then decides whether it is friendly or hostile. The left arrow key is for Friendly and the right arrow key is for Hostile. The next screen provides feedback. It shows the subject's decision, and the correct answer.

tabkey ---	**Stimulus** --->	*arrowkey* ---	**Feedback** --->	*tabkey*
start trial		friend, hostile		start next trial

Session 2: Training on Aircraft Engagement. This session consists of 104 trials of engagement decisions, 52 in each weapon control mode (tight, free). In this section when the aircraft

is presented, the subject decides whether to shoot at it or not. The left arrow key is designated "No Fire" and the right arrow key is designated "Fire". Unknown aircraft (i.e. aircraft not learned as friendly or hostile) are presented in this session. The next screen will again present feedback. This feedback screen will show the weapon control mode (tight, free), aircraft type (friend, hostile or unidentified), the subject's response and the correct answer.

tabkey --- **Stimulus** ---> *arrowkey* --- **Feedback** ---> *tabkey*
start trial fire, no fire start next trial

Session 3: Aircraft Engagement, Stimulus Only. Session 3 is the first of two test sessions. The task in Session 3 is again target engagement. The subject will be presented with a total of 60 trials (30 tight, 30 free) and will respond with a decision of Fire or No Fire. There is no feedback between stimulus presentations in this session. The screen displays "Hit tabkey when ready for next scenario."

Ready for ---> *tabkey* --- **Stimulus** ---> *arrowkey*
next scenario fire, no fire

start trial start next trial

Session 4: Aircraft Engagement With Priming. In Session 4, the subjects in the experimental groups will be presented with the priming information. The subjects viewed the screen as long as they wished. The information pertained to the aircraft to be

identified on that trial. The subject will press the tab key and the aircraft will be presented. The subject will respond once again with Fire or No Fire. There are 216 trials in this session (108 tight, 108 free). The control group in Session 4 will not receive the priming information, but repeat the procedure of Session 3 for their 216 Session 4 trials.

Ready for--> *tabkey*--	**Priming**--> *tabkey*--	**Stimulus**-->	*arrowkey*
next scenario	**Info**		fire, no fire
start trial			start next trial

The subjects will have periodic rest breaks as needed and the duration of the entire experiment should not exceed 120 minutes.

Experimental Design

A between subjects design will be used to present each of four primary conditions. The overall independent variable is information type. The four levels of this treatment are: (1) status information, (2) recommendation information, (3) status and recommendation information, and (4) no priming information (control condition). Within each condition, there are two additional within subject factors: weapon control mode (tight or free) and blocks of trials. Weapon control mode is blocked within subject and counter balanced across subjects. The blocks of trials was also a within subjects factor and will assist in observing the effects of practice and fatigue. Subjects are treated as random and all other factors are treated as fixed.

The dependent measures are: (1) accuracy, which is defined as the proportion of correct responses and (2) the response time to make the decision. The response time was measured from the onset of the target aircraft to the subject's response. Response time for only correct responses were used in the analysis. Subjects, during the test conditions, will experience 60 trials (30 tight, 30 free) with the stimulus only (no priming information) and 216 trials (108 tight, 108 free) with priming information. The control group (no prime condition) will complete these last 216 trials similarly to the first 60 (i.e., 276 trials of stimulus only).

Results

Introduction

The results will be presented in five separate sections. Those sections will be (1) training and stimulus only sessions results, (2) priming session results, (3) percent change results between stimulus only and priming sessions, (4) results of a more indepth look at information type performance across decision aid accuracy, and (5) a subjective assessment of subject strategy selection. Complete ANOVA tables are located in Appendix C.

Training and Stimulus Only Sessions

The baseline measures obtained from these first three sessions assured that there was no significant differences between groups prior to the introduction of the decision aid. Table 1 indicates the performance, in both accuracy and response time, of the four groups

for the two training sessions; training on aircraft identification and training on aircraft engagement. The groups are designated by the type of information they would eventually be using in the priming session. No significant difference between groups in these training sessions was found in the ANOVA of these results. Those results were as follows: training identification accuracy, $F(3,28)=1.33$, $p=.283$; training identification response time, $F(3,28)=.042$, $p=.988$; training engagement accuracy, $F(3,28)=1.45$, $p=.249$; and training engagement response time, $F(3,28)=.24$, $p=.868$.

Table 2 indicates the accuracy and response time performance of the four groups for session three, which tested the subjects on aircraft engagement without the assistance of the decision aid (i.e. stimulus only).

A repeated measures ANOVA was conducted with one between subjects factor (group) and one within subjects factor (weapon control mode). The interaction of weapon control mode and group was not significant for either accuracy, $F(3,28)=.667$, $p=.579$ or response time, $F(3,28)=.314$, $p=.815$. This lack of interaction allowed the collapsing across weapon control mode in this session. Once again no significant difference between groups was observed in terms of accuracy, $F(3,28)=.487$, $p=.694$ or response time, $F(3,28)=.910$, $p=.449$.

The results to this point in the analysis have provided some baseline measures and assured that there was no significant difference between the groups prior to the introduction of decision aiding information in Session Four.

Table 1. Accuracy and Response Times in Training Identification and Training Engagement Sessions.

Accuracy

Information Type	Training Identification	Training Engagement
Status	.99	.97
Recommendation	.99	.98
Status&Recommend.	.99	.99
Control	1.0	.98

Response Time (msec)

Information Type	Training Identification	Training Engagement
Status	1053	1279
Recommendation	1037	1218
Status&Recommend.	1049	1261
Control	1006	1129

Table 2. Accuracy and Response Times in Stimulus Only Session.

Accuracy

Information Type	Tight	Free	Mean
Status	.99	.98	.985
Recommendation	.97	.97	.97
Status&Recommend.	.98	.99	.985
Control	.97	.98	.975

Response Time (msec)

Information Type	Tight	Free	Mean
Status	1050	1084	1067
Recommendation	885	850	867
Status&Recommend.	995	934	964
Control	883	882	883

Priming Session

Repeated measures ANOVAs were then conducted on the results of the session in which three groups were assisted by a decision aid (priming session). Subjects nested in groups (based on the type of information they received from the decision aid) and

crossed by weapon control mode and blocks of trials. Separate ANOVAs were conducted for both accuracy and response time.

Accuracy. Table 3 presents the accuracy data for the priming session. It presents the accuracy data for each group in terms of weapon control mode as well as the mean accuracy for the whole session. The main effect of information type was not significant, $F(3,28)=.463$, $p=.71$. Likewise, the main effect of blocks of trials was not significant, $F(3,28)=.723$, $p=.541$. The main effect of weapon control mode was significant, $F(1,28)=4.625$, $p=.040$. Subjects were less accurate in weapon control mode Free. It appears that the subjects become more prone to making mistakes when they are allowed more freedom to engage aircraft, kind of a "trigger happy" effect.

Table 3. Accuracy in Priming Session.

	Accuracy		
Information Type	Tight	Free	Mean
Status	.99	.97	.98
Recommendation	.96	.97	.965
Status&Recommend.	.98	.96	.97
Control	.98	.97	.975
	.9775	.9675	

Response Time. Table 4 presents the response time data for the priming session. It presents the response time data for each group in terms of blocks of trials, as well as the mean response time for the whole session. There was no main effect of weapon control mode, $F(1,28)=2.142$, $p=.154$ and no significant interaction between weapon control mode and information type, $F(3,28)=.035$, $p=.991$. This allows the weapon control modes to be collapsed and the analysis to be conducted irrespective of weapon control mode. The main effect of information type was not significant, $F(3,28)=5.04$, $p=.683$, however, there was a main effect of blocks of trials with $F(3,84)=8.74$, $p=.0001$.

Table 4. Response Times in Priming Session.

Information Type	Response Time (msec)				
	Blocks				
	1	2	3	4	Mean
Status	860	720	681	755	754
Recommendation	715	663	613	645	659
Status&Recommend.	765	706	664	697	708
Control	810	778	828	800	804
	787.5	716.8	696.5	724.3	

Figure 1 illustrates the effect of practice across trials. The response times for the subjects, in the three conditions in which they are assisted by the decision aid, decline for the first three blocks of trials.

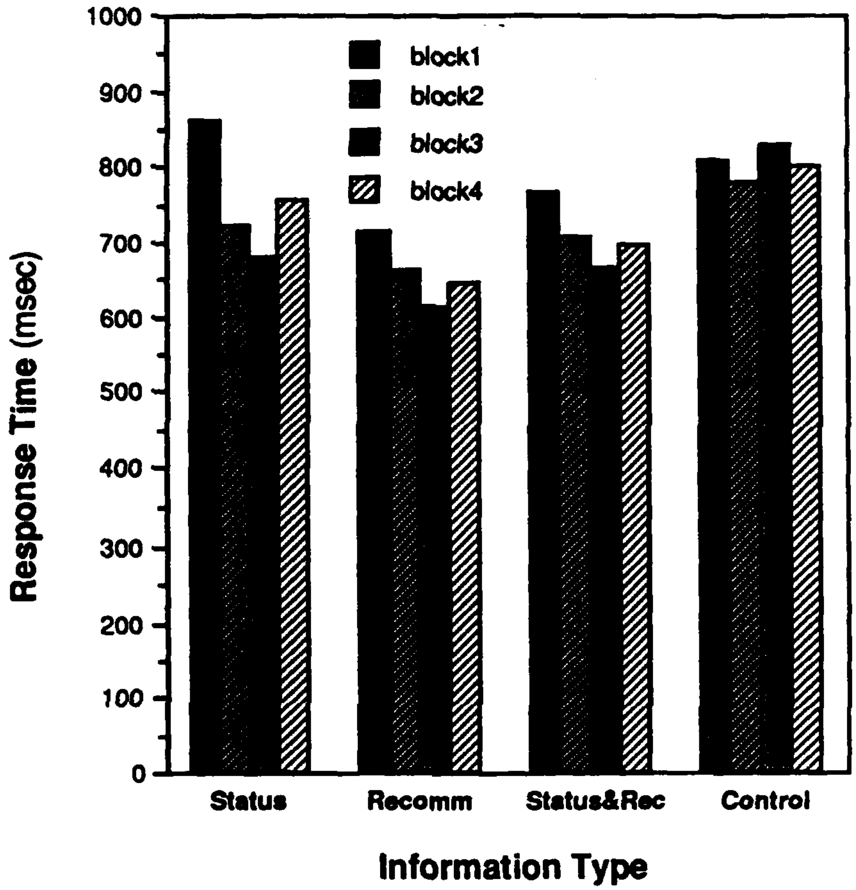


Figure 1. Main Effect of Blocks of Trials in the Priming Session.

Percent Change Results

Analysis of the percent change between the Stimulus Only and Priming sessions was also conducted for response times. This analysis compared the percent change between the means of the Stimulus Only data and the means of the Priming session data. Table 5 depicts the results of this analysis. It shows that the groups

receiving assistance from the decision aid all demonstrated a much greater decrease in response time than the control group.

Table 5. Percent Change in Response Times between Stimulus Only Session and Priming Session.

	Response Time		
Information Type	Stimulus Only	Priming	Percent Change
Status	1067	754	-29.3
Recommendation	867	658	-24.0
Status&Recommend.	964	708	-26.6
Control	882	803	-9.0

Figure 2 pictorially represents this response time decrease associated with the use of a decision aid with the three groups receiving assistance from the decision aid showing a much greater decrease in response time than the control group.

The ANOVA showed a significant difference in percent change between groups, $F(3,28)=3.37$, $p=.032$. A post hoc analysis showed that the control group was significantly different than each of the other groups, but none of the groups receiving decision information were significantly different from each other. A descriptive analysis of the effects of practice are presented in Appendix D.

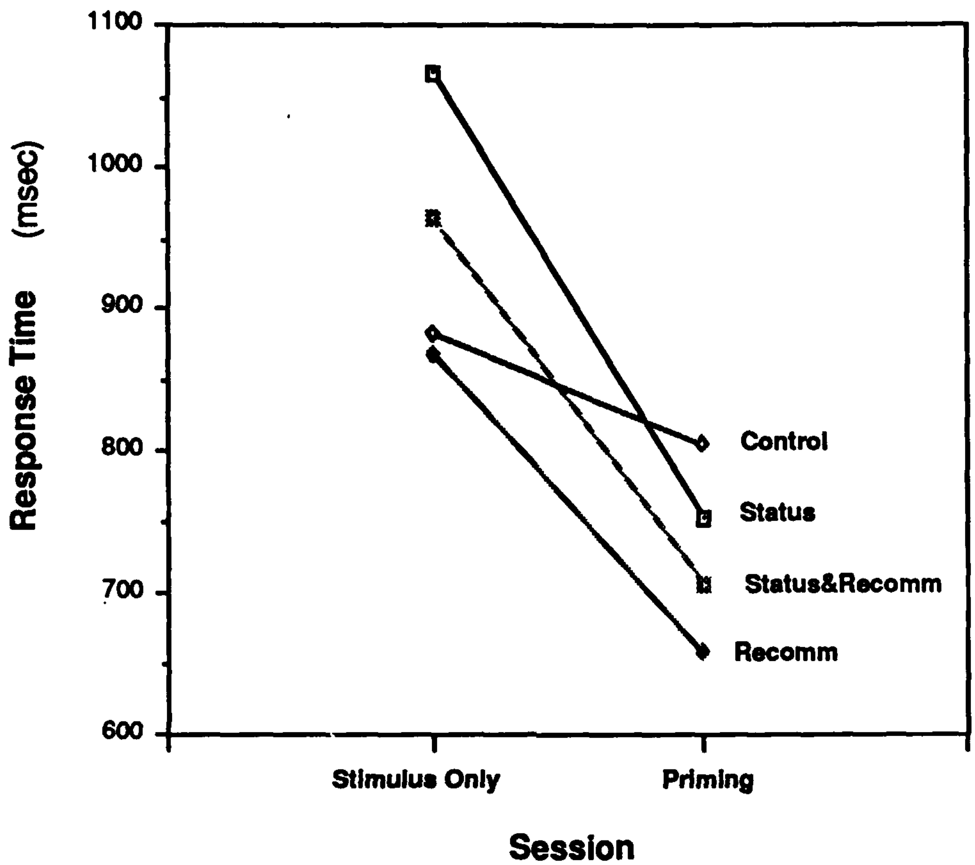


Figure 2. Overall Percent Change between Stimulus Only Session and Priming Session for each Information Type.

Indepth Analysis of Information Type

An analysis was conducted to determine if accuracy and response times were affected by the accuracy of the decision aid for each of the information types. Table 6 shows these results. The table shows the accuracy and response time for each information type as a function of the level of accuracy of the information

presented by the decision aid. The three levels of accuracy are correct, no help, and incorrect. The main effect of accuracy level of the decision aid was significant for both accuracy, $F(1,21)=7.52$, $p=.012$ and for response times, $F(1,21)=5.27$, $p=.032$. The main effect of information type was not significant for either accuracy, $F(2,21)=1.71$, $p=.329$ or response times, $F(2,21)=.037$, $p=.964$. The interaction of information type and accuracy level of the decision aid was not significant for either accuracy, $F(2,21)=1.08$, $p=.358$ or response times, $F(2,21)=.563$, $p=.578$.

Table 6. Accuracy and Response Times for each Information Type as a Function of the Accuracy of the Decision Aid .

	Accuracy		
Information Type	Correct	No Help	Incorrect
Status	.985	.979	.953
Recommendation	.973		.797
Status&Recommend.	.985	.957	.859

	Response Time		
Information Type	Correct	No Help	Incorrect
Status	701	848	812
Recommendation	622		992
Status&Recommend.	650	806	861

Figure 3 illustrates the accuracy of the subjects in each of the information types as a function of the level of accuracy of the decision aid. Although not statistically different, a descriptive analysis appears to indicate a trend in which status information results in the highest accuracy across all levels of accuracy of the decision aid.

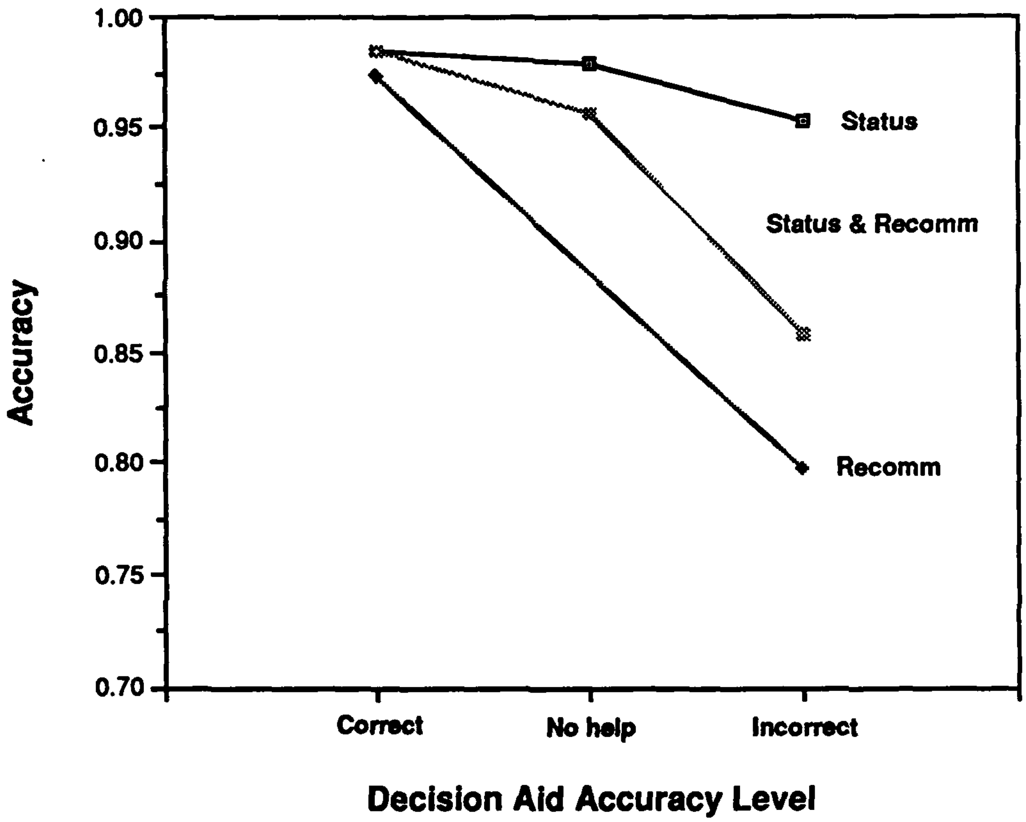


Figure 3. Accuracy of each Information Type as a Function of the Accuracy of the Decision Aid.

Figure 4 illustrates the response times of the subjects in each of the information types as a function of the level of decision aid accuracy. Again in a descriptive analysis, it appears that when the decision aid is correct, all three information types are nearly the same. When the decision aid is incorrect, status information and status and recommendation information have nearly identical response times; however the response times when presented with an incorrect recommendation are higher.

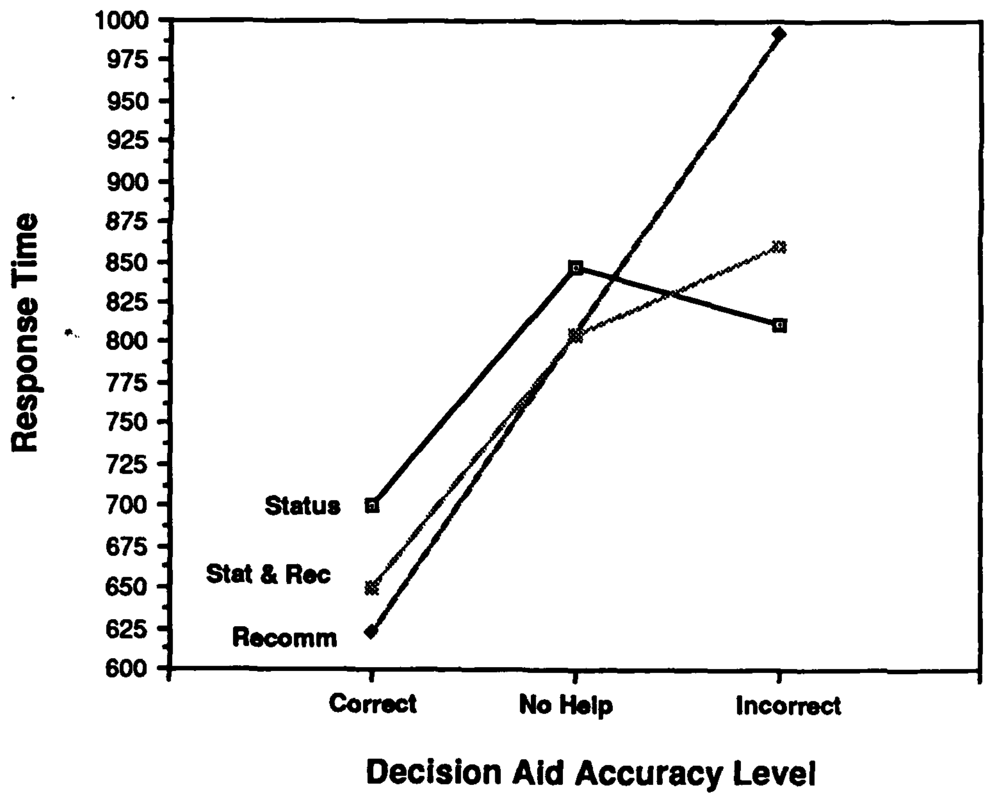


Figure 4. Response Times for each Information Type as a Function of the Accuracy of the Decision Aid.

Statistically, the results show that the accuracy of the subject decreased as the accuracy of the decision aid decreased. Descriptively, the greatest decrease occured when subjects received a recommendation. The decrease was smallest when subjects received status information, with status and recommendation information resulting in an intermediate decrement. Those subjects presented with only status information responded correctly in 95% of those situations where the decision aid provided incorrect information. Subjects presented with status and recommendation information, and recommendation information only responded correctly 86% and 80% of the time respectively. It appears that subjects presented with status information were able to recover more effectively when the decision aid presented incorrect information. A post hoc analysis did show that the accuracy of the Status group and the Recommendation group, when the decision aid was incorrect, were not significantly different, $F(1,21)=2.24$, $p=.149$. It appears that a large within group variance, possibly caused by a small sample size, washed out the significant difference here.

The same pattern can be seen in the response times. Statistically, the response times increased as the information from the decision aid goes from correct to no help to incorrect. Descriptively, the response times for status information and status and recommendation information drop in a similar pattern and are not as affected by incorrect information from the decision aid as those receiving recommendation information. An incorrect recommendation increased the response time by almost 30%. Once

again, it appears as though a large within group variance washed out the significant difference here as well.

An interesting tradeoff further illustrates the potential hazards when recommendation information is provided. Two of the eight subjects in the recommendation group and one in the status and recommendation group chose a strategy that strongly adhered to the recommendation of the decision aid. In this situation, the subject responded with the recommended action as soon as the stimulus appeared. This lead to a steep decrease in response time, but an accompanying rise in the percentage of incorrect responses when the decision aid provided an incorrect recommendation. Their percent change in response time from not having assistance to being assisted by the decision aid and the corresponding percentage of incorrect responses when the decision aid was incorrect are:

Table 7. Speed-Accuracy Tradeoff Associated with Strategy Selection.

Subject	Information Type	Percent Change in Response Time	Percent Incorrect when Decision Aid is Incorrect
22	Recomm	48%	50%
30	Recomm	70%	75%
19	Status&Recomm	40%	62.5%

The average percentage incorrect when the decision aid was incorrect for the other 21 subjects was 6%. A one way ANOVA showed that there was a significant difference between these

subjects and the other 21 subjects, $F(2,21)=105.16$, $p.<0001$. This clearly shows that, when provided with a recommendation, some people will choose this blind adherence strategy, and there is a cost associated with the speed increase, namely having very little chance of catching an incorrect recommendation.

Strategy Selection

An analysis of the post experiment questionnaire was conducted and the strategy used by each subject was determined. Strategies were determined by mapping the subject's comments to the description of the strategies. This analysis resulted in the following breakdown of strategy selection; recall there is only one strategy for those who received status information. Descriptions of the strategies are presented in Chapter 4.

Table 8. Results of Subjective Strategy Assessment.

Strategy	No. of Subjects	Accuracy	Response Time (msec)
S	8	.98	754
R_a	1	.963	497
R_b	4	.984	872
R_c	2	.93	375
S/R_a	3	.97	633
S/R_b	3	.99	839
S/R_c	1	.926	437

This analysis failed to determine the strategy for the one remaining subject in each of the recommendation information condition and the status and recommendation information condition. This chart shows that response times for the R_c and S/R_c strategies were extremely fast with an accompanying low accuracy whereas the R_b and S/R_b strategies have slower response times but higher accuracy.

Chapter 5
DISCUSSION AND CONCLUSIONS

Introduction

The main objective of this study was to investigate the effect of decision aiding on decision making performance. The major research questions were posed to accomplish this main objective. They were:

(1) Determine the effectiveness of decision aiding in facilitating both more accurate and quicker decisions

(2) Determine which type of decision information is most effective

This research has shown that, in this particular decision making environment, decision aiding does have an impact on the decision making process. Decision aiding significantly reduces the time to make a decision. All three types of decision information resulted in significantly faster decision making than no decision information.

When examining the specific types of information presented, status information seems to come to the forefront as the information type that shows the most promise. It reduces the time to make a decision, provides strategy stability, was most favorably viewed by the subjects, as well as quite possibly allowing easier recovery from faulty information from the decision aid. Recommendation information appears to be the most undesirable. It does, on average, reduce the time to make a decision, but clearly has some negative traits. The most glaring negative trait is strategy instability. One main strategy does not reduce decision making time, while the other main strategy greatly reduces the decision making time with almost

no chance of catching an incorrect recommendation before responding. Subjects also report locus of control problems, as well as not particularly liking recommendation information. Status and recommendation information holds the middle ground, benefitting from the positive aspects of status information and the negative aspects of recommendation information. Each of the research issues will now be presented in greater detail.

The Effectiveness of Decision Aiding

Will the performance of the decision maker be enhanced by the presentation of information related to the decision problem (i.e., is decision aiding effective in facilitating both more accurate and quicker decisions)? If one considers the amount of improvement that results from providing decision aiding information, there is evidence that a decision aid can reduce the amount of time to make a decision. In this experiment, response times decreased from Session Three, where the decisions were made without the assistance of the decision aid to Session Four, where assistance was provided (See Table 5 and Figure 2). The decrease was significant; the groups who were assisted by the decision aid were approximately three times faster than the control group.

The potential benefits are predicted by the priming literature and are related to the time to make a decision. The research in semantic priming (Meyer and Schvaneveldt, 1971,1976; Neely, 1977; Seidenstadt, 1982) suggested that decision aiding could enhance the decision making process, at least with respect to the time required to make a decision. Priming occurs when activation of a concept

positively affects processing of related concepts. This positive affect on processing results in a shorter time to make a decision. Since the purpose of a decision aid is to present information to a decision maker in an attempt to enhance performance, decision aiding is then extremely analogous to priming. Subjects in this research were likewise required to make a decision about a concept that was presented following various types of primes (from a decision aid). An analysis of the cognitive components of the tasks in the word recognition and problem solving studies and the decision making task of this research bear striking similarity. Since the cognitive task structure in this research is analogous to that in the earlier priming studies, the semantic priming research would suggest that decision aiding should enhance the decision making process, at least with respect to the time required to make a decision.

The decision support system research predicts enhanced total system performance if there is a "cognitive-coupling" between the human and the automated subsystem. This coupling is not display content independent but in fact depends greatly upon the manner in which the automated subsystem presents information to the human. Therefore the predictions are directly linked to the type of information displayed by the decision aid. This will be discussed in more detail when the selection on the best decision information is presented.

The repeated measures ANOVA of the Priming Session appeared to indicate that the decision aid had no effect on performance. Tables 3 and 4 report the accuracy and response times for the three groups with the assistance of decision aiding and the

control group. These results showed that the decision aid did not significantly affect the decision maker's ability to make either more accurate or quicker decisions. If critical inquiry into this research topic would have stopped here, one would have concluded that performance was, in fact, not enhanced enough to warrant the cost of designing and developing such a decision support system. Such a conclusion, however, would have been a mistake, since a slightly different approach to the analysis uncovered the potential benefits of a decision aid.

Selecting the Best Decision Information

Given that decision aiding is better than no aid, The question of selecting the appropriate decision aiding information becomes important. The second research issue of interest is related to the effectiveness of each type of information.

It has previously been established that the decision aid increased the speed of decision making by approximately three times that of the control group. However, that speed increase was very similar across all three types of information. How then can the most effective information type be determined? The following three areas were examined in an attempt to determine the best type of decision information: (1) accuracy and response times for each information type at the different levels of accuracy of the decision aid (correct, no help, and incorrect), (2) subject's strategy selection, and (3) subjects protocols.

Statistically, the results show that the accuracy of the subject decreased as the accuracy of the decision aid decreased. Descriptively, the greatest decrease occured when subjects received a recommendation. The decrease was smallest when subjects received status information, with status and recommendation information resulting in an intermediate decrement. Those subjects presented with only status information responded correctly in 95% of those situations where the decision aid provided incorrect information. Subjects presented with status and recommendation information, and recommendation information only responded correctly 86% and 80% of the time respectively. It appears that subjects presented with status information might be able to recover more effectively when the decision aid presents incorrect information. A post hoc analysis did show that the accuracy of the status group and the recommendation group, when the decision aid was incorrect, were not significantly different, $F(1,21)=2.24$, $p=.149$. It appears that a large within group variance, possibly caused by a small sample size, washed out the significant difference here (See Figure 4).

The same pattern can be seen in the response times. Statistically, the response times increased as the information from the decision aid goes from correct to no help to incorrect. Descriptively, the response times for status information and status and recommendation information drop in a similar pattern and are not as affected by incorrect information from the decision aid as those receiving recommendation information. An incorrect recommendation increased the response time by almost 30%. Once

again, it appears as though a large within group variance washed out the significant difference here as well (See Figure 5).

A person's strategy in using decision information is also a critical issue, since the choice greatly affects overall performance in a task, especially with respect to tradeoffs between accuracy and speed. The analysis of the subjective assessments of subject strategy showed that various strategies are indeed utilized when recommendation or status and recommendation information is presented by the decision aid. The means, for accuracy and response time for each of the strategies, were computed and mapped to the predictions made in Chapter 4. The predictions with the corresponding strategy are presented below. The analysis showed that when strategies were identified from the questionnaire and associated with performance, there is a very close correspondence to the predictions.

Accuracy

$(R_c = S/R_c) < NP < (S = R_a = S/R_a) < (R_b = S/R_b)$

.93 .926 .97 .98 .963 .97 .984 .99

Response Time

$(R_c = S/R_c) < (S = R_a = S/R_a) < NP < S/R_b < R_b$

375 437 754 497 633 803 839 872

The key point to be stressed is the fact that recommendation information and status and recommendation information lend themselves to the utilization of different strategies, two of which are at opposite ends of the speed-accuracy tradeoff. Notice that the response times for the R_c and S/R_c strategies were extremely fast with an accompanying low accuracy and the R_b and S/R_b strategies have slower response times but higher accuracy.

An example of this interesting tradeoff further illustrates the potential hazards when recommendation information is provided. Two of the eight subjects in the recommendation group and one in the status and recommendation group chose a strategy that strongly adhered to the recommendation of the decision aid. In this situation, the subject responded with the recommended action as soon as the stimulus appeared. This lead to a steep decrease in response time, but an accompanying rise in the percentage of incorrect responses when the decision aid provided an incorrect recommendation. Their percentage of incorrect responses when the decision aid was incorrect were significantly worse than the rest of the subjects. This clearly shows that, when provided with a recommendation, some people will choose this blind adherence strategy, and the cost associated with the speed increase is that of reducing the chance of catching an incorrect recommendation.

This strategy analysis points to another positive aspect of status information. It is stable. Status information does not lend itself to dichotomous strategies and unpredictable performance.

Lastly, some observations made by the subjects shed some light on the way they felt about working with the decision aid in general and with the different types of information in particular.

In general, many subjects were skeptical about working with the decision aid, and had more trust in their own judgement. This seems reasonable since they had little experience in working with a decision aid and especially this one in particular. Recall that the actual accuracy of the decision aid was 96%. Of the 24 subjects working with the decision aid, two thirds of them perceived the accuracy of the decision aid as less than it actually was, seven of the subjects estimated the accuracy between 60-75%, and 87% thought they were more accurate than the decision aid. In fact, 87% of those working with the decision aid were more accurate than the decision aid in the Stimulus Only Session. Tolerance for decision aid mistakes was extremely low and subjects lost confidence in the aid quickly (i.e. after only one error or perceived error in many cases). This resulted in many subjects indicating that they would rather do the task themselves. Finally, five subjects mentioned that the use of color as the presentation medium might be better than having to read the words that convey the information from the decision aid.

Also as part of the questionnaire (Appendix B), subjects were asked to rate the way they felt about being assisted by the decision aid on a scale of 1 (negative) to 10 (positive). The overall average was 5.11, with the information type averages being: status (5.36), recommendation (4.12), and status and recommendation (5.87). About the only thing this shows is that, were ambivalent towards the

decision aid and that recommendation information was "liked" less than the other two.

The summarized comments by the groups presented with the different information types follows. Those presented with status information generally said that the decision aid was helpful. Some of the comments were: "It was helpful, it gave me a headstart on what I was looking for;" "the decision aid was helpful when I was unsure about the aircraft, I had no problems overriding the decision aid;" and "I felt it was useful in recognition, but did not rely on it." The group presented with a recommendation were generally not very pleased. Many had negative comments. Some of those comments were: "It was more of a hindrance than help, wrong recommendations were annoying;" "I did not like the decision aid;" "I felt it was actually a handicap, sometimes I didn't let my own knowledge override the decision aid's recommendation;" "I was frustrated with an already made idea in my mind;" and "I didn't like it, it confused me. I like being in control and with the decision aid I felt like I wasn't." The group presented with a status and recommendation had mixed comments, which seem to generated based on what piece of information the subject focused on. Some of those comments were: "The recommendation made me hesitate;" "I ignored the recommendation part of the information and used the status information;" "I could not ignore the decisions aid's recommendation, I usually pressed the key suggested by the decision aid;" and "It was a good reference, but I didn't rely on it. I never really looked at the recommendation information."

Summing up these comments, it appears the people have a hard time estimating the actual accuracy of the decision aid, although they seem to be able to know they are more accurate and can, for the most part, know the times when the decision aid was wrong, many times after they made their response however. People are skeptical and even reluctant to trust computer assistance in tasks where they are responsible for the decision (especially if the aid is giving a recommendation). They are intolerant of mistakes and want the automated decision aid to be perfect. If it is not, they would rather do the task by themselves so as to not be further confused by an imperfect decision aid. Those working with the status information were generally positive. Those working with the recommendation information were definitely not favorable towards the aid and those working with status and recommendation information had mixed feelings toward the decision aid.

The analysis of the data from this experiment indicates that status information (i.e. friend, hostile, or unidentified) holds the most promise. This is in line with both the priming research and decision support system literature.

The priming research in both lexical decision tasks (Neely, 1977) and anagram problem solving tasks (Seidenstadt, 1982) showed that category primes resulted in faster response times. In this research, status information is equivalent to a category prime, because aircraft are members of categories approximately corresponding to the status information. This priming research suggests that status information should result in the priming effect,

positively affecting processing speed which should result in decreased time to make a decision.

In the decision support literature, Woods (1986) claims that the decision support system should act as an informative counsel. It should not be used to make or recommend solutions, but to aid the user in the process of reaching a decision. Smith (1981) claims that a machine locus of control can have strong negative effects on the user and total system performance. Sorkin and Woods (1985) state that the value of output from an automated subsystem is best considered as evidence to be used by the decision maker, rather than as a solution to be accepted or rejected.

Conclusions and Recommendations

In conclusion, this research has shown that, in this particular decision making environment, decision aiding does have an impact on the decision making process. Decision aiding significantly reduces the time to make a decision. All three types of decision information resulted in significantly faster decision making than no decision information.

When examining the specific types of information presented, status information seems to come to the forefront as the information type that shows the most promise. It reduces the time to make a decision, provides strategy stability, was most favorably viewed by the subjects, as well as quite possibly allowing easier recovery from faulty information from the decision aid. Recommendation information appears to be the most undesirable. It does, on average, reduce the time to make a decision, but clearly has some negative

traits. The first is strategy instability. One main strategy does not reduce decision making time, while the other main strategy greatly reduces the decision making time with almost no chance of catching an incorrect recommendation before responding. Subjects also report locus of control problems, as well as not particularly liking this type of decision information. Status and recommendation information holds the middle ground, benefitting from the positive aspects of status information and the negative aspects of recommendation information.

There are some methodological issues that need to be addressed and as well as the corresponding recommendations for future research on this topic. These issues potentially indicate why significant accuracy and response time differences may not have shown up in the Priming Session. The first is sample size. In this experiment, only eight subjects were assigned to each condition. This was thought to be enough, but in fact may not be.

The second and more serious issue centers around the aidability determination discussed by Hopple (1986). Recall in his paradigm, the decision situation variable focused on the complexity of the decision to be made and the quality of the data input. It appears that in this research, the quality of the data input was too high. In general the subjects were completing the task so quickly that the assistance from the decision aid was helpful, but not an appreciable amount. According to Hopple's paradigm, the high data input quality (i.e. aircraft stimuli) resulted in a lower impact by the decision aid than predicted. A recommended methodological adjustment would be to degrade the data input quality (i.e. make it

harder to identify the aircraft). This should increase the impact of the decision aid. The author is already working on this by considering the possibility of systematically decreasing the visibility and size of the stimuli.

The third issue is a also crucial one and one that was discussed in detail in the section on mediating factors in the decision process. It deals with the cognitive strategy subjects choose when presented with a certain type of information. Some of these strategies have dichotomous results in both accuracy and response time. When results are averaged across subjects receiving the same information type (e.g. recommendation), but using different strategies, the results make it hard to arrive at general conclusions about the overall effect of that information type without looking deeper.

APPENDIX A

STIMULUS SET

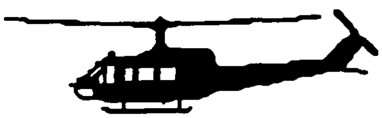
Friends

A7 Corsair

A10 Thunderbolt

AH1 Cobra

OH58 Kiowa



UH1 Iroquois

UH60 Blackhawk

F16 Fighting Falcon

C130 Hercules

F4 Phantom

F5 Freedom Fighter

Hostile

MIG17 Fresco

SU25 Frogfoot

MI24 Hind

MI4 Hound

MI6 Hook

MI8 Hip

MIG21 Fishbed

AN12 Cub

MIG27 Flogger D

SU24 Fencer

Unknown

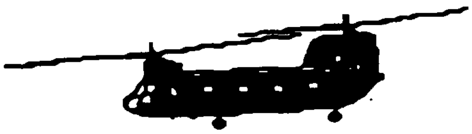
A4 Skyhawk

A6 Intruder

Alphajet

AV8 Harrier

BO 105



CH47 Chinook

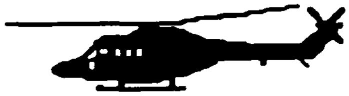
Buccaneer

F18 Hornet

G91

Lightning

Gazelle



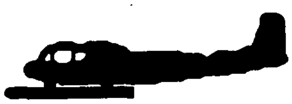
Lynx

IL28 Beagle

SU7 Fitter

OA37 Dragonfly

Wasp



OV10 Bronco

OV1 Mohawk

APPENDIX B

QUESTIONNAIRE

1. Did you use the information from the decision aid?

2. If so how much (in a % please)? If not, why?

3. Prior to the use of the decision aid, when I said the decision aid was very accurate, what did very accurate mean to you in terms of a % of the time you thought the decision aid would give you the correct answer (ie. how accurate did you think the decision was going to be)?

4. How accurate do you think the decision aid was (in a % please)?

5. Did you feel you were more accurate than the decision aid?

6. How did you use the information presented by the decision aid (ie. what strategy did you use to make your decision to shoot or not when you had the decision aid to assist you)? Use Back if needed.

7. Rate the way you felt about being assisted by the decision aid in this task. (circle the appropriate number and make comments if any)

negative ... positive

1 2 3 4 5 6 7 8 9 10

comments:

8. If you could design a decision aid to assist you in this task, what would you have it present to you? (check one).

___Status information only (ie. Friend, Hostile or Unidentified)
___Recommendation information only (ie. Fire or No Fire)
___A combination of Status and Recommendation information
___Nothing
___Something else(explain)________________________________

9. Any other comments please. Use back if needed.

APPENDIX C

ANALYSIS OF VARIANCE TABLES

Training Identification Session (Accuracy)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INFOTYPE	0.001	3	0.000	1.333	0.283
ERROR	0.004	28	0.000		

Training Identification Session (Response Time)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INFOTYPE	10766.375	3	3588.792	0.042	0.988
ERROR	2366075.500	28	84502.696		

Training Engagement Session (Accuracy)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INFOTYPE	0.002	3	0.001	1.453	0.249
ERROR	0.012	28	0.000		

Training Engagement Session (Response Time)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INFOTYPE	106912.625	3	35637.542	0.240	0.868
ERROR	4162210.250	28	148650.366		

Stimulus Only Session (Accuracy)

Main Effect of Information Type

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.003	3	0.001	0.487	0.694
ERROR	0.051	28	0.002		

Main Effect of Weapon Control Mode

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.000	1	0.000	0.438	0.513
ERROR	0.017	28	0.001		

Weapon Control Mode by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.001	3	0.000	0.667	0.579
ERROR	0.017	28	0.001		

Stimulus Only Session (Response Time)

Main Effect of Information Type

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	403609.672	3	134536.557	0.910	0.449
ERROR	4138589.063	28	147806.752		

Main Effect of Weapon Control Mode

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	3953.266	1	3953.266	0.181	0.674
ERROR	611140.063	28	21826.431		

Weapon Control Mode by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	20554.172	3	6851.391	0.314	0.815
ERROR	611140.063	28	21826.431		

Priming Session (Accuracy)

Main Effect of Information Type

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.010	3	0.003	0.463	0.710
ERROR	0.197	28	0.007		

Main Effect of Weapon Control Mode

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.007	1	0.007	4.625	0.040
ERROR	0.043	28	0.002		

Weapon Control Mode by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.007	3	0.002	1.645	0.202
ERROR	0.043	28	0.002		

Main Effect of Blocks

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.003	3	0.001	0.723	0.541
ERROR	0.099	84	0.001		

Block by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.014	9	0.002	1.287	0.256
ERROR	0.099	84	0.001		

Weapon Control Mode by Block Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.006	3	0.002	1.828	0.148
ERROR	0.097	84	0.001		

Weapon Control Mode by Block by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.008	9	0.001	0.797	0.620
ERROR	0.097	84	0.001		

Priming Session (Response Time)

Main Effect of Information Type

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	740982.449	3	246994.150	0.504	0.683
ERROR	.137222E+08	28	490077.370		

Main Effect of Weapon Control Mode

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	88171.879	1	88171.879	2.142	0.154
ERROR	1152728.047	28	41168.859		

Weapon Control Mode by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	4271.699	3	1423.900	0.035	0.991
ERROR	1152728.047	28	41168.859		

Main Effect of Blocks

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	293679.543	3	97893.181	8.743	0.000
ERROR	940500.953	84	11196.440		

Block by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	180928.879	9	20103.209	1.796	0.081
ERROR	940500.953	84	11196.440		

Weapon Control Mode by Block Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	45197.543	3	15065.848	1.267	0.291
ERROR	999011.516	84	11892.994		

Weapon Control Mode by Block by Information Type Interaction

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	134516.816	9	14946.313	1.257	0.273
ERROR	999011.516	84	11892.994		

Percent Change (Accuracy)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
INFOTYPE	7.799	3	2.600	0.192	0.901
ERROR	379.940	28	13.569		

Percent Change (Response Time)

SOURCE	SUM-OF-SQUARES	DF	MEAN-SQUARE	F-RATIO	P
HYPOTHESIS	0.199	3	0.066	5.897	0.003
ERROR	0.315	28	0.011		

APPENDIX D
EFFECTS OF PRACTICE

A second analysis looked at percent change, but each session was broken down into its two blocks (not tight and free but first and second in temporal sequence). Table 9 shows the results of analyzing the percent change in this fashion. This table shows the percent change both within the Stimulus Only and Priming sessions as well as the percent change between sessions.

Table 9. Percent Change in Response Times within and between Stimulus Only and Priming Sessions.

	Percent Change in Response Time		
Information Type	Stimulus Only	Stimulus Only->Priming	Priming
Status	-11.65	-19.58	-12.79
Recommendation	-5.17	-22.04	+1.67
Status&Recommend.	-11.16	-17.53	-10.56

The percent change within the sessions indicates the proportion of the change in response times associated with practice during that session. The percent change between the two sessions indicates the proportion of response time decrease associated with the decision

aid. By subtracting the average of the within session changes from the between session change, the resulting value will be that decrease in response time due to the decision aid for that particular information type. The results of this procedure are:

Status	=	-7.36 %
Recommendation	=	-18.54 %
Status & Recommendation	=	-6.67 %

Figure 5 shows that the slope of the line between the sessions is steeper than the slope of the line within the sessions. Thus the improvement identified in the previous percent change analysis is not merely the result of practice, but also a function of the assistance of the decision aid.

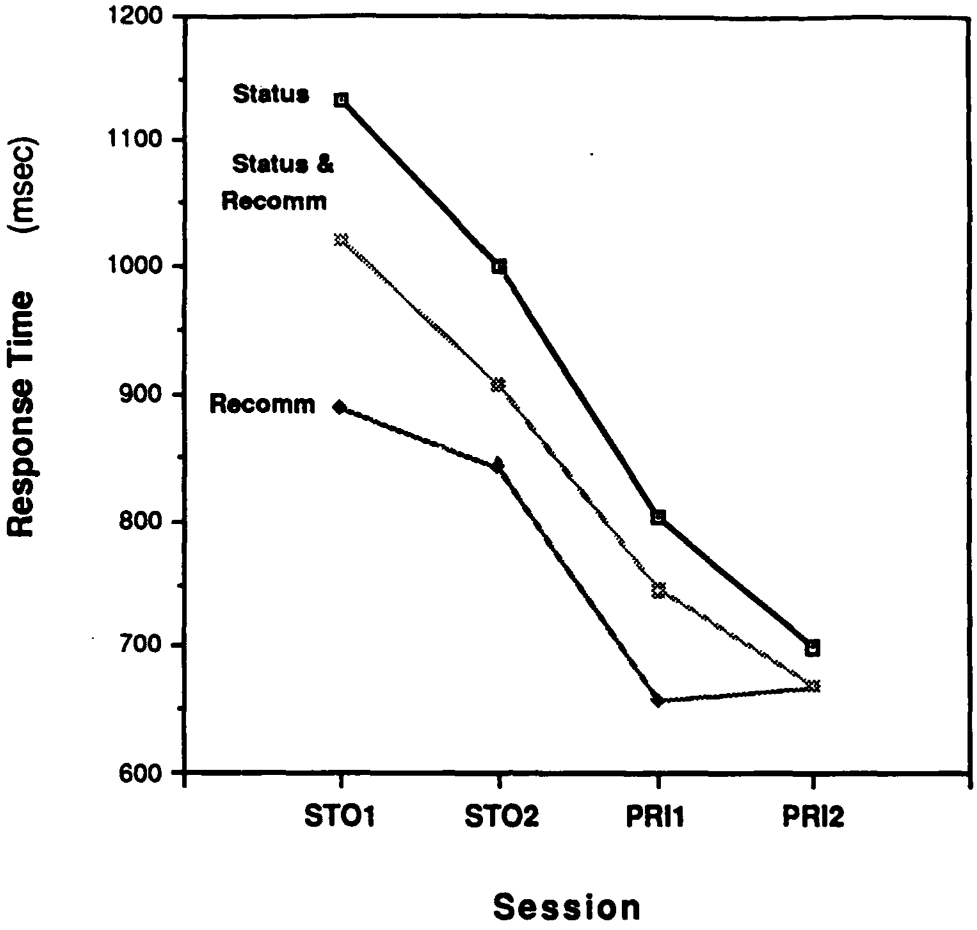


Figure 5. Detailed Percent Change within and between Stimulus Only and Priming Sessions for each Information Type.

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